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Measurement of the bending of thin inclined nanowires as a method for determining elastic modulus

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Recently, researchers are interested in semiconductor nanowires, which may have unusual mechanical and electrophysical properties [1]. In a number of studies it was shown that the Young's modulus of thin nanowires (ZnO[2], GaAs[3]) can significantly differ from the tabulated values of the Young's modulus of bulk materials. In this paper, scanning probe microscopy (SPM) method is presented that allows measuring the Young's modulus of thin and flexible nanowires, which consists in measuring the bending profiles of nanowires in the precise force control regime. Using this approach, it was possible to measure the Young's modulus of thin InP tapered nanowires with (i) wurtzite structure and (ii) zinc blende structure.

Samples with thin tapered InP nanowires were studied, differing both in their geometric parameters and in their crystal structure (wurtzite or zinc blende). The samples were grown by chemical vapor deposition method by the vapor-liquid-solid mechanism with catalytic gold droplets on a Si substrate at temperature of T=450°C. The geometric parameters of the nanowires were determined by scanning electron microscopy and then by scanning probe microscopy methods. The type of crystal structure of InP nanowires was determined from electron diffraction data.

For precision bending of nanowires in this work the “PeakForce” regime [4] was applied. This mode was specially created to minimize the SPM-probe force acting on the surface and makes it possible to study "very soft objects" including nanowires with a small bending stiffness. In the experiment, we had the opportunity to reduce the SPM-probe force acting on the surface down to 0.05 nN and maintain it during scanning with a high degree of accuracy. The use of scanning with ultra-small forces made it possible to obtain noiseless images of inclined InP nanowires without their bending. This was an important step, necessary for further accurate measurement of nanowires bending.

In this work we propose the method of measuring the bending profiles w(x) on inclined InP nanowires with different SPM-probe forces F_{peak} acting on the nanowire. With increasing values of the magnitude of the peak force (F_{peak}=0.05nN, 1nN, 2nN, 5nN, 10nN) the deflection of the nanowire will increase, which will lead to a change in the scanning topography of the inclined nanowire. We can assume that the deflection of the nanowire is close to zero when working with an ultra-small force (0.05nN) acting on the nanowire. Therefore, when subtracting from the topographic profile of the inclined nanowire obtained with the force 5 nN ($h(x)_{5nN}$) of the profile obtained with a force of 0.05 nN ($h(x)_{0.05nN}$), we obtain the nanowire bending profile w(x) corresponding to the force 5nN ($w(x)_{5nN}=h(x)_{5nN}-h(x)_{0.05nN}$). During our measurements, we observed a linear increase in the bending profiles with increasing values of the peak force $w \sim F_{peak}$. This means that in the range of applied forces there is a linear bending of the nanowire for which Hooke's law is valid. Once the set of deflection profiles is measured along the nanowire, these profiles are divided by the values of the corresponding forces and profile of inverse stiffness is obtained $1/k(x)=w(x)/F$.

To analyze the inverse stiffness profiles of thin tapered InP nanowires a formula was used that relates the value 1/k(x) of a tapered nanowire and its Young's modulus E. Using this approach, it was possible to measure the Young's modulus of tapered InP nanowires with a wurtzite structure and zinc blende structure. The measured value of Young's modulus of wurtzite InP nanowires was E_{WZ}=130±30 GPa. It should be noted that the experimental measurement of Young's modulus of wurtzite InP was performed for the first time. The theoretical calculations of the Young's modulus in wurtzite InP (E_{WZ_theory} = 120 GPa) are in good agreement with the obtained experimental results.

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